GLOBULAR CLUSTERS IN DWARF GALAXIES

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ABSTRACT

Data are presently available on the luminosities and half-light radii of 101 globular clusters associated with low- luminosity parent galaxies. The luminosity distribution of globulars embedded in dwarf galaxies having $M_v > -16$ is found to differ dramatically from that for globular clusters surrounding giant host galaxies with $M_v < -16$. The luminosity distribution of globular clusters in giant galaxies peaks at $M_v \sim -7.5$, whereas that for dwarfs is found to increases monotonically down to the completeness limit of the cluster data at $M_v \sim -5.0$. Unexpectedly, the power law distribution of the luminosities of globular clusters hosted by dwarf galaxies is seen to be much flatter than the that of bright unevolved part of the luminosity distribution of globular clusters associated with giant galaxies. The specific frequency of globular clusters that are fainter than $M_v = -7.5$ is found to be particularly high in dwarf galaxies. The luminosity distribution of the LMC globular clusters is similar to that in giant galaxies, and differs from those of the globulars in dwarf galaxies. The present data appear to show no strong dependence of globular cluster luminosity on the morphological types of their parent galaxies. No attempt is made to explain the unexpected discovery that the luminosity distribution of globular clusters is critically dependent on parent galaxy luminosity (mass?), but insensitive to the morphological type of their host galaxy.

Subject headings: globular clusters: general

1. INTRODUCTION

It is the purpose of the present paper to see if the luminosity distribution of globular clusters depends on the luminosity (mass?) of their host galaxy. There are at least two reasons why such differences might be expected: (1) The evolutionary history of giant galaxies (which is believed to have been dominated by hierarchical merging) may have differed significantly from that of dwarf galaxies, and (2) cluster destruction by bulge and disk shocks is expected to be much more important in massive giants than it is in low mass dwarfs. Finally it is of interest to enquire if the luminosity distribution of the globular clusters hosted by dwarf galaxies is also a function of the morphological type of their parent galaxy. Recent investigations by Sharina, Puzia & Marakov (2005), by van den Bergh & Mackey (2004) and by Mackey & van den Bergh (2005) provide information on the luminosities M_v and half-light radii R_h of 101 globular clusters that are associated with host galaxies which are of intermediate or low luminosities. These data, which are collected in Table 1, have been restricted to hosts with luminosities fainter than $M_v = -18.9$. This limit was chosen so as to include the Large Magellanic Cloud ($M_v = -18.5$), while excluding M 33 ($M_v = -18.9$), for which the observational data on globular clusters are still both inhomogeneous and incomplete. Table lists (1) the name of the parent galaxy, (2) the de Vaucouleurs type, (3) the luminosity of this host galaxy, (4) the name of each cluster, (5) the absolute cluster magnitude M_v and (6) the projected distance of each cluster from the center of its host galaxy. Uncertain values are followed by a colon (:). Angular dimensions were converted to pc or kpc using the distances listed in van den Bergh (2000). Clusters with intrinsic colors $(V - I)_o < 0.70$ were excluded because of the high probability that they might actually be young open clusters. In Table 1 host galaxies with distance moduli $(m - M)_o < 28.0$, corresponding to a distance D < 4.0 Mpc, have been marked with an asterisk (*). The data for the more remote galaxies with D > 4.0 Mpc are probably more uncertain than are those for the globulars in nearer galaxies.

2. DATA SAMPLE

Sharina et al. have used HST images of 57 nearby low surface brightness galaxies to search for globular cluster candidates. The majority of the fields they searched were located in small clusterings of galaxies (M81 group, Sculptor group, CVn I cloud, Cen A group, NGC 3115 group, while 35% of their target galaxies were situated in the field. To enlarge the data sample information on globular clusters that are associated with dwarf members of the Local Group which is, in many respects, similar to the small galaxy groups studied by Sharina et al. has been added to the sample. As a result the present discussion deals with data that are homogeneous in the sense that they refer to objects in similar environments. The main conclusions about the luminosity distribution of globular clusters in dwarf galaxies would have remained unchanged (albeit at lower statistical weight) if the Local Group globulars (see Mackey & van den Bergh 2005) had not been added to the sample. These authors also noted that some of the characteristics of the globular clusters in Local Group dwarfs are shared by the Galactic globulars with $R_{gc} > 15$ kpc, i.e. those that lie outside of the main body of the Galaxy. This observation is consistent with the view that a significant fraction of this cluster population component consisting of objects that were tidally captured from now disrupted dwarf companions to the Milky Way System.

3. LUMINOSITY DISTRIBUTION OF GLOBULARS

Data on the luminosity distribution on globular clusters in various environments are summarized in Table 2 and are plotted in Figures 1 - 4. Figure 1 shows the normalized distribution of the luminosities of globular clusters associated with dwarf host galaxies having $M_v > -16$ that are situated at distances D $<$ 4.0 kpc. For such objects the sample should be reasonably complete down to $M_v \sim -5.0$. The figure shows a luminosity distribution that peaks near the completeness limit and then decreases monotonically

towards higher luminosities. A Kolmogorov-Smirnov test shows that there is only a 0.6% probability that the sample of globulars in dwarf galaxies at D < 4.0 Mpc, and the sample of Galactic globulars with $R_{gc} < 15$ kpc (which is plotted in Figure 4), were drawn from the same parent population of globular cluster luminosities.

Could the high frequency of faint globulars in dwarfs be due to the inclusion of highly reddened young open clusters in the sample? This appears very unlikely because all of the host galaxies for objects plotted in the figure are faint galaxies with $M_v > -16.0$. Such dwarfs are all probably quite metal-poor and are therefore expected to contain little dust. In other words the clusters with $(V - I)_o > 0.7$ are unlikely to be reddened young open clusters. The most luminous object in the sample (shown as an arrow) is NGC 6715 = M54, which is thought (Ibata, Gilmore & Irwin 1994) to be the remnant nucleus of the Sagittarius dwarf.

Figure 2 shows the luminosity distribution for the globular clusters associated with the more distant host galaxies that lie at D $\geq$ 4.0 Mpc. Probably due to incompleteness at faint magnitudes, the luminosity distribution for these objects peaks at a brighter value ($M_v \sim -6.2$) and then declines towards higher luminosities. The brightest object in this sample (which is plotted as an arrow) appears to be the nucleus of KK84, which has $M_v = -9.68$.

Figure 3 shows the normalized luminosity distribution for the globular clusters in the LMC ($M_v = -18.5$) and the SMC ($M_v = -17.1$). The globulars associated with these objects appears to have a peak at $M_v = -7.0$ or $M_v = -7.5$, i.e. the globular clusters in the Magellanic Clouds have a similar luminosity distribution to that of Galactic globular clusters with $R_{gc} < 15$ kpc, the luminosity distribution of which is shown in Figure 4. The luminosity distribution of the globular clusters in the main body of the Milky Way resembles that of the globulars in (mostly luminous) distant host galaxies for which Harris (1991)

found a peak frequency at $M_v \sim -7.5$. A Kolmogorov-Smirnov test shows no statistically significant difference between the luminosity distribution of the 17 globular clusters in the Magellanic Clouds and the luminosity distribution of the 110 Galactic globulars with $R_{gc} < 15$ kpc. The most luminous object in Fig. 4, which is plotted as an arrow, is ω Centauri, which is believed (e.g. Bekki & Freeman 2003; Tsuchiya, Dinescu & Korchagin 2003, and references therein) to be the nucleus of a now defunct dwarf galaxy.

The data discussed above show a strong dependence of the luminosity distribution of globular clusters on the absolute magnitudes of their parent galaxies. Giant and supergiant galaxies, i.e hosts with $M_v < -16$, appear to also have luminous globulars with a distribution that peaks near $M_v \sim -7.5$. On the other hand faint host galaxies with $M_v > -16$ exhibit a luminosity distribution that increases monotonically towards the observational completeness limit at $M_v \sim -5$. It is not yet clear to what extent the observed difference between the luminosity distributions of globular clusters in luminous and dim galaxies are intrinsic, or shaped by environmental factors. In other words are these differences due to the different galaxy formation scenarios (hierarchical mergers versus gas inflow), or were they the result of environmental factors, such as the preferential destruction of low mass clusters by the disk/bulge shocks (e.g. Aguilar, Hut & Ostriker 1988) in massive giant luminous galaxies?

The luminosity distribution of the globular clusters in faint hosts exhibits some similarities to that of the globular clusters in the outer halo of the Galaxies (van den Bergh 2000, p.229, Mackey & van den Bergh 2005). This observation lends support to the view that the globular cluster population in the outer Galactic halo at $R_{gc} > 15$ kpc consist of a mixture of (1) globular clusters that were initially associated with the main body of the Galaxy (2) other clusters that originally formed in galaxies with $M_v > -15$ and (3) a small admixture of very luminous objects that are the remnant cores of now defunct dwarf

galaxies.

The vast majority (27 out of 30) of the blue (presumably open) star clusters with $(V - I)_o < 0.7$, that are listed by Sharina et al. (2005), are situated in only two of the 57 objects that these authors studied. They are the dwarf irregular galaxies Holmberg IX (M_v = -13,8, D = 3.7 Mpc) and UGC 3755 ($M_v = -15.36$, D = 5.2 Mpc). Most of these blue clusters have absolute magnitudes in the range $-5.5 > M_v > -8.0$, where the lower luminosity limit is set by observational selection effects.

4. DEPENDENCE OF LUMINOSITY ON PARENT GALAXY TYPE

Almost all of the parent galaxies listed in Table 1 are either late-type objects with de Vaucouleurs types T = 6 to T = 10 (Scd - Ir) or early-type galaxies with T = -5 to T = -2 (E - S0). It is of interest to enquire if the luminosity distribution of globular clusters depends on their parent galaxy type. Such a dependence might perhaps have been expected if the early evolutionary history of galaxies is strongly correlated with their morphological types. Unexpectedly, examination of the data in Table 1 shows no obvious differences between the luminosity distributions of globular clusters in early-type and in late-type galaxies. However, an important caveat is that the present data sample is small. The very strong dependence of the globular cluster luminosity distribution on parent galaxy luminosity might therefore mask a weak dependence of the cluster luminosity distribution on host galaxy morphological type.

5. THE LUMINOSITY HALF-LIGHT RADIUS RELATION

In previous papers (van den Bergh & Mackey 2004, Mackey & van den Bergh 2005) we have shown that few Galactic globular clusters lie above and to the left of the line

$$\text{Log } R_h = 0.25 M_v + 2.95. \tag{1}$$

The clusters that do fall above the relation defined by Eqn. (1) are mostly objects suspected of being the cores of now defunct dwarf galaxies. Do these same conclusions also apply to the globular clusters associated with lower luminosity hosts? In an attempt to answer this question Figure 5 show a plot of the M_v versus R_h relation for globular clusters in the more-or-less complete sample of host galaxies with D < 4.0 Mpc. The vast majority of the objects plotted in this figure are seen to fall below and to the right of the line defined by Eqn. (1). Among the three exceptions is NGC 6715 (=M54), plotted as a plus sign, that is thought to be the nucleus of the Sagittarius system (Ibata, Gilmore, & Irwin, 1994), which - as expected - lies above this line.

Figure 5 also shows that the clusters associated with the LMC and the SMC (plotted as triangles) are systematically more luminous than are the globular clusters in the sample of globulars associated with the nearest faint dwarf galaxies. Finally Figure 6 shows the following: (1) There is little evidence for a correlation between the half-light radii and the luminosities of globulars in dwarf galaxies at D $\geq$ 4.0 Mpc. (2) The most luminous host galaxy in our sample is UGC 3755 (M_v = -15.4). The globular clusters in this galaxy (which are plotted as triangles) appear to have systematically smaller radii than do those of the globular clusters hosted by less luminous galaxies (which are plotted as circles). A K-S test shows only a 3% probability that the data for the UGC 3755 globulars, and those associated with the other dwarfs with D $\geq$ 4.0 Mpc, were drawn from the same parent population. Finally (3) it is puzzling that the globulars in the dwarf sample with D $\geq$ 4.0 Mpc do *not* appear to follow the upper limit defined by Eqn. (1), whereas the globular clusters associated with nearer galaxies having D < 4.0 Mpc (see Figure 5) mostly lie below this line. Contributing factors to the apparent difference between clusters with D < 4.0 Mpc and those with D$\geq$ 4.0 Mpc might be (i) distance errors for the most distant clusters and

(ii) systematic errors of the (small!) angular diameters measured for the objects in the most distant cluster sample. (4) The apparent nucleus of KK84, which is plotted as a plus sign in Figure 5 , lies well above and to the left of the line defined by Eqn. (1). This suggests that this object is indeed the nucleus of its host galaxy. Finally (5) it is of interest to note that many of the objects plotted in Figure 6 occupy a region in the Mv versus Rh diagram that appears to be similar to that occupied by the "faint fuzzies" (Larsen & Brodie 2000) in lenticular galaxies. A caveat noted previously is that both the distances, and the cluster radius measurements are particularly uncertain for the remote clusters having D > 4.0 kpc, It would be important to obtain both spectroscopic observations, and higher resolution images, of the extended objects plotted in Fig.6. Such measurements would enable one to establish if these objects are both physically and structurally similar to the faint fuzzies that Larsen & Brodie found to be associated with some lenticular galaxies.

6. SPECIFIC GLOBULAR CLUSTER FREQUENCY

The low-luminosity galaxies listed in Table 1 are remarkably rich in globular clusters. For the objects with D < 4.0 Mpc, that are fainter than $M_v = -15.0$, one finds 38 clusters in a parent galaxy population that has a total luminosity $M_v = -15.85$. This yields a specific frequency (Harris & van den Bergh 1981) of S = 17. Such a high value is, however, an overestimate because those galaxies that contain no globular clusters at all are not included in the total sample luminosity. However, an unbiased estimate of S can be obtained from a subset of the data by deriving the specific globular cluster frequency from the essentially complete Local Group data for galaxies with $M_v > -15.0$. For these objects one finds that all known individual Local Group (van den Bergh 2000, p.280) galaxies fainter than $M_v = -15.0$ have a combined luminosity of $M_v = -15.58$. This population contains 12 globular clusters , which yields a still rather high mean specific globular cluster frequency S

= 8 ± 3. This compares to 1 < S < 5 for the majority of nearby non-dwarf galaxies (Harris 1991). Part of this difference is, no doubt, due to gas loss from low-mass galaxies. In other words low-mass dwarf galaxies might actually be star poor rather than cluster rich.

It is of interest to note that only nine of the 42 clusters in Table 1 are brighter than $M_v = -7.5$. The high specific frequency found for the dwarfs with D < 4.0 Mpc is therefore almost entirely due to the numerous intrinsically faint globular clusters with $M_v > -7.5$. The results obtained above urgently raise the question whether the high frequency of faint globulars in low-luminosity galaxies is intrinsic, or if it is it due to environmental factors. Was the formation rate of low-mass clusters particularly high in dwarfs because they accumulated gas in a quiescent fashion? This appears unlikely because the quiescent dwarf irregular IC 1613 ($M_v = -15.3$) appears to contain few, if any, star clusters (Baade 1963, van den Bergh 1979). Alternatively one might suppose that either (1) the more violent processes associated with hierarchical merging in massive galaxies favored the formation of luminous globular clusters, and/or (2) that the destruction of faint globulars was favored in massive galaxies. Perhaps the most reasonable interpretation of the present results is that normal cluster formed in dwarf hosts by gradual increase in the density and pressure of the ISM, and/or by the slow loss of the internal energy in molecular clouds. On the other hand clusters in the (starbursting) giant galaxies that generated massive globular clusters long ago might have formed when shocks were driven inward by ionization fronts generated by cosmic reionization at z ∼ 6 (van den Bergh 2001, Keto, Ho & Lo 2005), or more recently during violent starbursts triggered by mergers.

7. CLUSTER LUMINOSITY SPECTRUM

If globular clusters form from the cores of giant molecular clouds (Harris & Pudritz 1994, McLaughlin & Pudritz 1996), then one might expect them to produce globular

clusters having a power law luminosity distribution of the form.

$$N(L) \; \alpha \; L^{\Gamma}, \tag{2}$$

with Γ in the range -1.7 to -2.0. This expectation is confirmed (e. g. McLaughlin 2003) for the bright end of the luminosity distributions of the globular cluster systems associated with giant galaxies. The frequency of less luminous, and hence less massive, clusters falls below the predictions of Equation (2). The reason for this (Aguilar, Hut & Ostriker 1988) is thought to be that the least massive clusters in giant galaxies are efficiently destroyed by the disk and bulge shocks in massive galaxies. The disruptive effects of disk and bulge shocks will be greatly reduced in dwarf galaxies in which cluster velocities are small and the bulge/disk masses are low. Such dwarfs might therefore be expected to contain globular cluster systems that show a power law cluster luminosity distribution down to quite faint cluster luminosity limits.

Figure 7 shows a plot of the distribution of the luminosities of the 38 globular clusters with D $<$ 4.0 Mpc, that are hosted by dwarf galaxies with $M_v > -16.0$. These clusters do indeed appear to exhibit a power law luminosity distribution, however, one that has a much shallower slope than that which is observed among the globulars hosted by luminous galaxies. The data plotted in Figure 7 unexpectedly show a power law luminosity distribution with Γ α -0.7, rather than one with the expected value $-1.7 > \Gamma > -2.0$. It is not yet clear why the globular clusters in faint galaxies have such a shallow power law luminosity distribution.

8. CONCLUSIONS

Presently available data a show dramatic difference between the luminosity distributions of globular clusters associated with dwarf galaxies having parent galaxies fainter than

$M_v = -16$, and the luminosity distributions of globulars hosted by luminous giant galaxies that are brighter than $M_v = -16$. Perhaps surprisingly the globular clusters associated with the Magellanic Clouds (LMC $M_v = -18.5$, SMC $M_v = -17.1$) resemble those hosted by giant galaxies. It would be particularly interesting to extend observational data on the globulars in UGC 3755 ($M_v = -15.36$) to fainter limits to see if this cluster-rich intermediate luminosity galaxy has a globular cluster system with characteristics that are intermediate between those surrounding giant and dwarf galaxies.

The cluster systems hosted by giant galaxies are found to have a peak frequency at $M_v \sim -7.5$, whereas the luminosity distribution of globular clusters hosted by dwarf galaxies is seen to rise monotonically down the completeness limit of the data at $M_v \sim -5$. The globular clusters hosted by dwarf galaxies are found to have a luminosity distribution that may be described by a power law. However, for unknown reasons, this power law in dwarf galaxies is found to be much shallower than that which is observed among the brightest (most massive) globulars that are associated with giant galaxies.

In both giant and dwarf galaxies the cores of defunct dwarf galaxies, such as ω Centauri and NGC 6715, lie above and to the left of the relation given by Equation (1). Most of the clusters hosted by the well-observed clusters hosted by galaxies at D < 4 Mpc are also found to fall below the line defined by Equation (1). It would be interesting to obtain additional observations of the globulars in dwarf galaxies that appear to fall in the same region of M_v versus R_h space as do the "faint fuzzies" of Larsen & Brodie. The specific globular cluster frequency in dwarf galaxies is found to be much higher than that in giants. This difference is almost entirely due to an excess of very faint globular clusters in dwarf Galaxies with $M_v > -16$.

Unexpectedly, the present data show no evidence for a dependence of the luminosity distribution of globular clusters on the morphological type of their host galaxies. It will

be a challenge to theory to explain why the luminosities of globular clusters depend so critically on the luminosity (mass?) of their parent galaxy, while being insensitive to the morphological type of their host galaxy.

This paper represents an extension of previous work done in collaboration with Dougal Mackey. I thank him for his wise comments and voluminous e-mail correspondence on various issues related to globular clusters. It is also a pleasure to thank Peter Stetson for writing a few special computer programs that were used for some calculations in the present investigation. Finally I also wish to thank a particularly helpful anonymous referee.

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Table 1. Globular Clusters in Dwarf Galaxies

Galaxy	M_v (gal)	Cluster	M_v	R_h(pc)	D (kpc)
DDO 53* T=10	-13.74	3-1120	-5.88	6.7	0.3
BKN3N* T=10	-9.53	2-863	-5.23	6.8	1.3
KDG73* T=10	-11.31	2-378	-5.75	8.3	1.5
KK77* T=-3	-12.21	4-939	-5.01	3.7	1.2
		4-1162	-5.37	6.5	1.6
		4-1165	-5.69	7.8	1.6
KDG61* T=-1	-13.58	3-1325	-7.55	4.7	0.0
KDG63* T=-3	-12.82	3-1168	-7.09	6.0	0.2
DDO78* T=-3	-12.75	1-167	-7.23	7.4	1.5
KK84 T=-3	14.40	2-785	-7.30	11.6	2.5
	3-705	-7.45	9.2	1.7	2.5
		3-705	-7.45	9.2	1.7
		3-830	-9.68	10.6	0.0
		3-917	-7.52	10.4	1.3
		4-666	-8.37	10.6	2.4
		4-967	-6.81	12.0	4.1
KK112 T=10	-12.28	3-976	-5.93	9.1	0.3
		4-742	-6.21	11.8	1.5
		4-792	-6.77	15.0	1.4
E490-017 T=10	-14.91	3-1861	-7.38	6.4	0.2
		3-2509	-5.69	8.4	0.8

Table 1—Continued

Galaxy	M_v (gal)	Cluster	M_v	R_h(pc)	D (kpc)
KK065 T=10	-13.32	3-1095	-6.75	11.5	0.3
UGC4115 T=10	-14.13	2-1042	-6.00	11.9	1.7
		3-784	-7.53	9.4	1.2
		4-1477	5.37	8.0	2.6
UA438* T=10	-11.94	3-2004	-8.67	3.7	0.2
		3-3325	-5.96	3.7	0.4
UGC3755 T=10	-15.36	2-652	-8.22	5.5	1.8
		2-675	-5.75	8.1	1.2
		2-863	-6.93	5.2	1.0
		3-739	-8.67	5.7	0.8
		3-768	-5.42	5.7	0.8
		3-1256	-7.77	8.6	0.4
		3-1257	-8.71	6.2	0.4
		3-1611	-7.48	7.5	0.3
		3-1732	-6.09	10.0	0.6
		3-1737	-6.71	8.3	0.1
		3-2168	-7.63	8.7	0.4
		3-2204	-6.07	6.6	0.4
		3-2398	-6.17	8.5	0.8
		3-2401	-7.54	12.0	0.7
		3-2403	-6.79	6.8	0.9

Table 1—Continued

Galaxy	M_v (gal)	Cluster	M_v	R_h(pc)	D (kpc)
		4-566	-6.25	8.6	1.3
LMC* T=9	- 18.5	NGC 1466	-7.26	4.8	7.3
		NGC 1754	-7.09	3.2	2.3
BK6N* T=-3	-11.92	2-524	-5.40	4.4	0.8
		4-789	-5.60	4.5	1.2
Garland* T=10					
	...	1-728	-8.26	3.2	1.2
Holmberg IX* T=10		3-1565	-5.31	4.1	0.1
	-13.8	3-1932	-6.61	9.4	0.4
		3-2373	-6.04	7.9	0.6
E540-030* T=-1	-11.84	4-1183	-5.37	6.2	1.6
E294-010* T=-3	-11.40	3-1104	-5.32	6.7	0.1
KK027* T=-3	-12.32	4-721	-6.36	7.5	0.6
Sc22 T=-3	-11.10	2-879	-6.11	12.2	0.9
		2-100	-5.90	8.3	2.2
		4-106	-6.05	4.9	1.9
DDO113 T-10	-12.67	2-579	-5.60	7.9	1.5
		4-690	-5.27	6.5	0.6
UGC7605 T=10	-13.88	3-1503	-6.44	12.2	0.4
KK109 T=10	-10.19	3-1200	-5.87	4.4	1.0
UGC8308 T=10	-12.48	2-1198	-5.52	7.5	0.9

Table 1—Continued

Galaxy	M_v (gal)	Cluster	M_v	R_h(pc)	D (kpc)
		3-2040	-6.62	9.1	1.2
		4-893	-6.30	5.1	1.6
		4-971	-5.62	8.3	1.8
KK211* T=-5	-12.58	3-917	-6.86	6.3	0.5
		3-149	-7.82	6.1	0.0
		2-608	-8.04	5.0	1.8
		2-883	-7.07	8.3	1.4
		2-966	-9.80	5.7	0.9
		3-1062	-6.10	9.1	0.4
KK200 T=9	-12.74	3-1696	-5.68	9.2	1.2
KK84 T=-3	-14.40	2-785	-7.30	11.6	2.5
		3-705	-7.45	9.2	1.7
		3-830	-9.68	10.6	0.0
		3-917	-7.52	10.4	1.3
		4-666	-8.37	10.6	2.4
		4-967	-6.81	12.0	4.1
KK112 T=10	-12.28	3-976	-5.93	9.1	0.3
		4-742	-6.21	11.8	1.5
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		4-1477	-5.37	8.0	2.6
UA438* T=10	-11.94	3-2004	-8.67	3.7	0.2
		3-3325	-5.96	3.7	0.4
UGC3755 T=10	-15.36	2-652	-8.22	5.5	1.8
		2-675	-5.75	8.1	1.2
		2-863	-6.93	5.2	1.0
		3-739	-8.67	5.7	0.8
		3-768	-5.42	5.7	0.8
		3-1256	-7.77	8.6	0.4
		3-1257	-8.71	6.2	0.4
		3-1611	-7.48	7.5	0.3
		3-1732	-6.09	10.0	0.6
		3-1737	-6.71	8.3	0.1
		3-2168	-7.63	8.7	0.4
		3-2204	-6.07	6.6	0.4
		3-2398	-6.17	8.5	0.8
		3-2401	-7.54	12.0	0.7
		3-2403	-6.79	6.8	0.9

Table 1—Continued

Galaxy	M_v (gal)	Cluster	M_v	R_h(pc)	D (kpc)
		4-566	-6.25	8.6	1.3
LMC* T=9	-18.5	NGC 1466	-7.26	4.8	7.3
		NGC 1754	-7.09	3.2	2.3
		NGC 1786	-7.70	3.3	2.2
		NGC 1835	-8.30	2.4	1.2
		NGC 1841	-6.82	10.8	12.9
		NGC 1898	-7.49	8.4	0.5
		NGC 1916	-8.24	2.2	0.2
		NGC 1928	-6.06:	5.6:	0.3
		NGC 1939	-6.85:	7.6:	0.6
		NGC 2005	-7.40	2.7	0.8
		NGC 2019	-7.75	2.9	1.1
		NGC 2210	-7.51	3.5	3.8
		NGC 2257	-7.25	10.5	7.6
		Hodge 11	-7.45	8.6	4.1
		Reticulum	-5.22	19.3	9.9
		ESO121-SC03	-4.37	10.0	8.4
SMC* T=-5	-17.1	NGC 121	-7.89	5.4	2.4
Fornax* T=-5	-13.1	No.1	-5.32	11.8	1.6
		No.2	-7.03	8.2	0.9
		NGC 1049	-7.66	4.4	0.6

Table 1—Continued

Galaxy	M_v (gal)	Cluster	M_v	R_h(pc)	D (kpc)
		No.4	-6.83	3.5	0.2
		No.5	-6.82	4.4	1.6
Sagittarius* T=-5		Pal. 2	-8.01	5.4	···
	-13.8	NGC 4147	-6.16	2.4	···
		NGC 6715	-10.01	3.8	0.0
		Ter. 7	-5.05	6.6	2.1
		Arp 2	-5.29	15.9	2.4
		Ter. 8	-5.05	7.6	3.5
		Pal. 12	-4.48	7.1	···

Table 2. Luminosity distributions of globular clusters in galaxies different environments.

Mv	D < 4.0 kpc	D > 4.0 kpc	LMC + SMC [b]	Galaxy [c]
	Parent $M_v > -17.0$ [a]			$R_{gc} < 15$ kpc
-10.25	1[d]	0	0	1[d]
-9.75	1	1[d]	0	1
-9.25	0	0	0	7
-8.75	2	2	0	8
-8.25	2	2	2	13
-7.75	4	5	4	18
-7.25	4	4	6	19
-6.75	4	7	2	19
-6.25	4	10	1	9
-5.75	5	9	0	5
-5.25	11	3	1	2
-4.75	0	0	0	3
-4.25	1	0	1	2
>-4.0	0	0	0	3
total	38	43	17	110

[a]D

[b]D

[c]Data from Mackey & van den Bergh (2005)

[d]Galaxy nucleus?

Fig. 1.— Normalized frequency distribution of globular clusters with D < 4.0 kpc that are located in parent galaxies with $M_v > -16$. The luminosity function of these clusters is seen to rise monotonically down to the completeness limit at $M_v = -5.0$. The object marked with an arrow is NGC 6715, which is thought to be the nucleus of the Sagittarius dwarf.

Fig. 2.— Normalized frequency distribution for globular clusters with D $\geq$ 4.0 kpc, that are situated in host galaxies that are fainter than $M_v - 16.0$. The distribution peaks at $M_v \sim -6.2$. Below this value the sample is incomplete. The brightest object in the sample is the cluster 3-830, which appears to be the nucleus of KK84.

Fig. 3.— Normalized luminosity distribution for the globular clusters in the LMC ($M_v = -18.5$) and the SMC ($M_v = -17.1$). The sample is seen to peak at $M_v \sim -7.3$, i.e. close to the peak value for the globular clusters in the inner region of the Milky Way System ($M_v = -20.9$:).

Fig. 4.— Normalized luminosity distribution for the Galactic globular clusters with $R_{gc} < 15$ kpc. These data exhibit a peak at $M_v \sim -7.0$. The brightest object in the plot, which is marked with an arrow, is ω Centauri - which is thought to be the stripped nucleus of a dwarf galaxy.

Fig. 5.— Relation between M_v and R_h for globulars in faint hosts that are located at D < 4.0 Mpc. The figure shows that most of the clusters in these nearby dwarfs lie below and to the right of the line defined by Eqn. (1). The cluster NGC 6715, which is believed to be the nucleus of the Sagittarius dwarf spheroidal galaxy, is plotted as a plus sign. The globulars in the Magellanic Clouds (which are plotted as triangles) are seen to be systematically more luminous than those in the less luminous nearby host galaxies.

Fig. 6.— Relation between M_v and R_h for globulars in faint hosts with D $>$ 4.0 Mpc. These data show no obvious correlation between cluster luminosity and cluster radius. Furthermore, a significant fraction of all of these clusters lie above and to left of the line defined by Eqn. (1). In this respect these clusters differ from those in the Galaxy and at D $<$ 4.0 Mpc. The plus sign is the nucleus of the dwarf galaxy KK84. The dotted arrows show the region containing the “faint fuzzies” in lenticular galaxies. Many of the objects in the plot are seen to fall within the domain occupied by the “faint fuzzies”. The globulars hosted by UGC 3755 (which is the brightest host in this sample) are plotted as triangles. Note that these objects in UGC 3755 appear to be systematically smaller than those in the other less luminous dwarfs.

Fig. 7.— Luminosity distribution of 38 globular clusters associated with dwarf galaxies having $M_v > -16.0$ and D $<$ 4.0 Mpc. The clusters are seen to have a power law distribution down to the completeness limit at $M_v \sim -5.0$. The distribution has an exponent $\Gamma \sim$ -0.7, which is much flatter than the values $-1.7 > \Gamma > -2.0$ that are encountered in the globular cluster systems hosted by giant galaxies. The luminosities in the figure have been normalized in such a way that an object with $M_v = 0.0$ has L = 1.